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Occurrence of *Armillaria* spp. in Forests of the Northern Rocky Mountains

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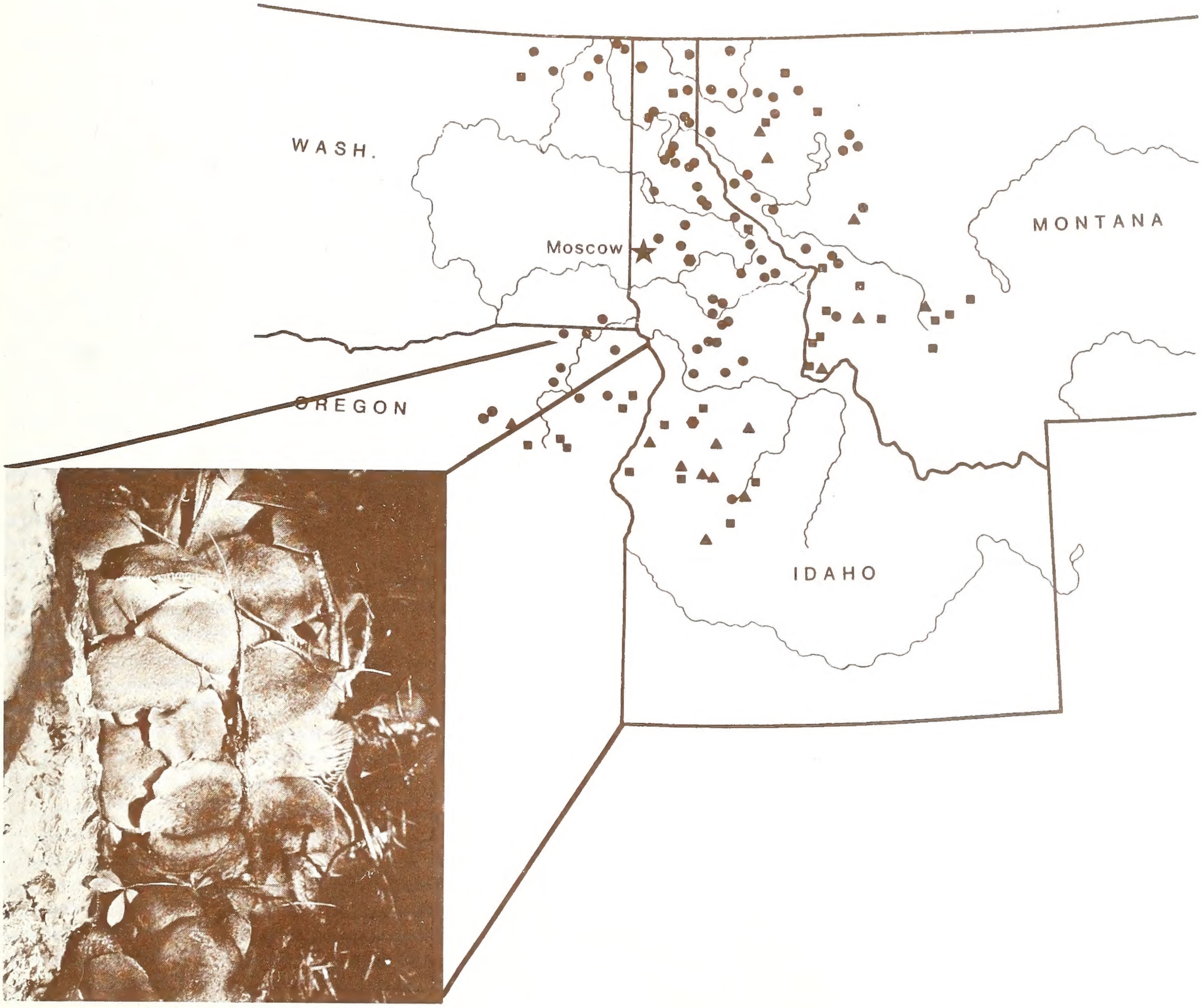

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RESEARCH SUMMARY

The distribution of *Armillaria* spp. on National Forests of the Northern Rocky Mountains was investigated through random installation and inspection of 0.04-ha plots. Woody plant species living and dead were searched for fans, rot, or rhizomorphs typical of *Armillaria* spp., which were then verified through laboratory cultures. *Armillaria* occurrence was found to be related to a root rot risk-rating system based on the current system for classifying vegetational communities. *Armillaria* spp. were absent from the warm and dry juniper and pinegrass habitat types (h.t.'s) of the Douglas-fir series, the cold and dry beargrass and grouse whortleberry h.t.'s of the subalpine fir series, the cold and wet twisted stalk h.t.'s of the subalpine fir series, and the frost-pocket dwarf huckleberry h.t.'s of both the Douglas-fir and subalpine fir series.

Data linking *Armillaria* spp. to host and ecological function (epiphyte, saprophyte, or pathogen) were also recorded. These data will be reported in future papers after more reliable methods have been developed for assigning isolates to their correct taxonomic positions. We expect to find that certain *Armillaria* spp. are pathogenic on conifers in general or maybe even on specific conifer species, and that their geographic distribution is related to habitat type.

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INTRODUCTION

Root disease caused by various species of *Armillaria* is integral to most forested ecosystems worldwide (Wargo and Shaw 1985). As early as 1930, the fungus was recognized as a root pathogen in the Western United States (Hubert 1931, 1950; Johnson 1976). *Armillaria* commonly occurs as rootlike rhizomorphs growing on plant debris or is epiphytically attached to root systems of dead, diseased, or healthy host plants (Garrett 1960; Kile 1980; Leach 1939; Raabe and Trujillo 1963; Redfern 1973). Isolates obtained from such rhizomorphs, as well as isolates obtained from mycelial fans, rotten wood, and sporophores, can belong to species or specific clones whose apparent pathogenicity varies (Kile 1983; Rishbeth 1982; Wargo and Shaw 1985).

Severity of this root disease tends to increase as management intensifies. Partial cutting (Filip 1977; Filip and Goheen 1982; Redfern 1978), excessive grazing (Bega 1979), and fire control (Shaw and others 1976) all appear linked to increased activity of *Armillaria* spp. In Queensland, Australia, *Armillaria* spp. were found in nearly all stumps after clearcutting of a first-rotation introduced pine forest (Anon. 1982). Chemical and mechanical killing of hardwoods is linked to increased *Armillaria* activity (Pronos and Patton 1977; Swift 1972) in remaining conifers. Conifers planted to replace clearcut conifer or hardwood forests have experienced significant *Armillaria*-related mortality (Redfern 1978; Shaw and Roth 1978). *Armillaria* spp. frequently interact with insects and other pathogens (Dunbar and Stephens 1975; Madziara-Borusiewicz and Strzelecka 1977; Singh and Raske 1983; Wargo 1977, 1981) to compound losses. Slash disposal methods may also affect *Armillaria* spp.; woody debris incorporated into the soil can be a significant source of new infections (Garrett 1960; Raabe and Trujillo 1963). Even method and quality of planting (Rykowski 1981) can influence damage caused by this organism (Singh and Richardson 1973).

Aside from total removal of woody plant parts followed by clean cultivation, no technique has proved effective in controlling this pathogen (Pawsey 1973; Shaw and Roth 1978). Other promising management techniques are the planting of tolerant or resistant species or varieties; application of chemicals or fire; site amendments (including extraction of wood from the soil) prior to planting; and judicious selection of cutting times based on overall risk prediction. Effective application of such techniques requires much new knowledge of the biology, genetic architecture, physiology, and ecology of hosts and the causal agent. We particularly need to know variation in pathogenicity and virulence of the pathogen and variation in resistance of the hosts.

Many studies have reported that in terms of geographic distribution and host range, *Armillaria* spp. are ubiquitous (Ehrlich 1939; Hobbs and Partridge 1979; Hubert 1950; Swift 1972). The primary objective of such studies has been to determine the degree of its damage rather than the distribution of the fungus. Typical examples are Carey and others (1984), Williams and Marsden (1982), and James and others (1984), wherein sample points were selected by location of symptomatic trees or root disease centers.

What do we need to know about *Armillaria*? How extensive is the distribution of various species of *Armillaria* and to what extent are these species pathogenic or saprophytic? Useful information could also include host, pathogenic or saprophytic condition, and taxonomic affiliation of each fungal sample. Knowing probability of occurrence (such as a proportion of 0.04-ha plots) of pathogenic and nonpathogenic entities in relation to other ecological criteria could serve as the basis for classifying forest lands according to risk of specific host species, given various management actions. Control measures could be similarly categorized.

In 1983, we began a study of population level genetic and ecological interactions between *Armillaria* and its conifer and hardwood hosts. The two primary objectives of this research were (1) to predict *Armillaria* risk by habitat type, host species, and stand management history; and (2) to develop ways for assessing genetic and physiologic responses between host and fungus populations in Northern Rocky Mountain forests. This paper reports on the occurrence of vegetative parts of *Armillaria* spp. by climax series.

MATERIALS AND METHODS

Plots 0.04 ha in size were randomly selected from forested lands of the Northern Rocky Mountains as follows: A 1.27-cm grid was placed over 1,270-cm:1,609-m maps of 15 Northern Rocky Mountain National Forests. Random coordinates were drawn 15 times for each National Forest to locate 15 sections (1,609-m^2 blocks) on each. Aerial photo indexes were used to obtain 12,000:1, 16,000:1, or 24,000:1 photos of the selected sections. Each photo was matched in turn with drainage patterns and other features common to the photos and maps for locating the target section. Section lines were drawn to scale on the photograph and measured in millimeters. Next, two random numbers were chosen between 1 and the scaled length (about 100 mm, dependent on photo scale) of a section border. The northwestern corner of the section was used as the zero intersection on which to locate the randomly drawn coordinates. The point described by the coordinates was used as the plot center.

Plots were selected according to two criteria: (1) site must be forested or have once supported forests, and (2) site must be less than 1.6 km from a trail or road. Plots were selected in the order that sections were selected, eight plots per National Forest. If the first selection was unsuitable, then a ninth plot was selected. This process was continued until all 15 sections within a National Forest were used. If eight satisfactory plots were not found, then the first discarded section was used again, with the northeastern corner as the zero intersection for the randomly drawn coordinates. The process continued until eight satisfactory plots were obtained on each of the 15 National Forests.

A line was drawn from the plot point on the photo to a landmark along a road or trail. This became the witness point. The distance between witness point and plot was scaled from the photo.

In the field, the photo was oriented, and the bearing from the witness point to the plot was obtained from the photo and recorded. A string-line recorder was used to measure (nearest meter) the scaled distance from the witness point to the plot, and a compass was used to follow the designated bearing. If a stream or some other impassable barrier blocked the chosen path to the designated plot, the complementary bearing and distance were taken in the opposite direction. In a few cases, the designated distance was halved for the same reason. Ultimately, the main criterion was that the plot be located at the end of a measured line of predetermined length. The eight randomly chosen plots per National Forest provided a total of 120 plots. An additional 19 auxiliary plots were taken in areas where *Armillaria* spp. were not found on random plots. This provided a more encompassing sample for future study of geographic variation of the fungus and enhanced our knowledge of specific occurrence patterns.

After traveling the designated distance, a plot center was established at a tree or other major feature. Using a compass and a string-line recorder, a plot 20 m on a side (400 m^2) was laid out with sides parallel and perpendicular to the bearing. Key indicator plants were recorded, as were aspects of topography, so that habitat type (based on potential climax vegetation) of the plot could be determined (Pfister and Arno 1980). The vegetation was photographed. Roots of cut trees, wind-broken trees, and dead trees (from seedling to mature) were inspected for rhizomorphs, fans, characteristic rotten wood, and root resinosis. The root systems of at least one living and apparently healthy representative of all major hardwood and conifer species on the site were inspected for fans, rotten wood, and attached rhizomorphs. The inspection consisted of exposing the root collar and major roots to a depth of about 0.3 m and a lateral spread of 0.5 to 1 m, then looking for rot and fans by chopping. Living and apparently healthy conifers that were selected for increment boring (cores to be used later to study relationships between *Armillaria* activity and site productivity) were also inspected for fans, resinosis, and attached rhizomorphs. These trees were thoroughly inspected around half their root crowns and along all major roots attached to the inspected portion. This inspection required 1 to 3 hours to complete. Any insect or disease problems were also noted.

Sections of rhizomorphs 0.1 to 0.5 m in length were collected and their source recorded. They had to be physically attached to the host plant to be recorded as being from that host. Rhizomorphs not so attached were recorded as taken from the soil. The samples were placed in disposable plastic culture tubes and taken to a field laboratory (motel room). Each evening the day's collections (rhizomorphs, bark fans, or rotten wood) were rinsed two times in tap water, then sterilized for 10 minutes in a 20 percent commercial bleach solution. The bleach solution was decanted and collections rinsed by filling the tube with sterilized water, vigorously agitating, and decanting. They were rinsed a second time and allowed to set for 10 minutes. The final rinse was decanted, and sterilized rhizomorphs were removed and cut into 5- to 10-mm segments. These were placed, one each, in 10-mL plastic culture tubes containing 1.5 percent malt extract medium. After 1 month, all collections were verified for rhizomorph production in culture as well as other cultural attributes typical of the genus *Armillaria*. Some fans were taken directly from their underbark location and placed in the 10-mL tubes.

All plots were classified by habitat type with dichotomous keys based on lists of indicator plants (Cooper and others in press; Pfister and others 1977; Steele and others 1981). This classification was verified by an ecologist through study of the plot photos and plant lists. Habitat type of the few plots that occurred on fresh or regenerated clearcuts was determined by inspection of adjacent stands. The plots were lumped by climax series for some analyses and by habitat type for others. The proportion of *Armillaria* occurrence on any host and as epiphytic rhizomorphs on hardwoods and conifers was calculated. Also calculated was the proportion of epiphytic rhizomorphs found on: (1) healthy conifers by species, (2) healthy hardwoods (including dead parts of healthy plants), and (3) dead conifer materials by plot.

RESULTS

Armillaria Distribution

Chi-square analysis of the climax series revealed significant heterogeneity regarding the probability of encountering *Armillaria* on randomly selected 0.04-ha plots (table 1). Heterogeneity seemed to be associated with plot productivity, as measured by average site index (height of dominant and codominant trees at 50 years = SI in table 1). We therefore arrayed the plots by habitat type in order of increasing productivity within climax series (table 2). The two least productive series (ABLA and PSME)(see table 2 footnote for species code definitions) showed a definite discontinuous distribution pattern. Hot-dry, cold-dry, and frost-pocket habitat types appeared not to support *Armillaria*. Two plots on cold-wet habitat types (ABLA/STAM and ABLA/CACA) also failed to yield

Table 1—Incidence of *Armillaria* spp. signs and/or symptoms on randomly selected 0.04-ha plots classified by climax vegetation series on 15 Northern Rocky Mountain National Forests

Climax indicator	Average site index[1]	Number of plots	Number with *Armillaria*	Proportion with *Armillaria*
Subalpine fir	16.15	[2]35	15	0.42
Douglas-fir	16.46	[3]18	6	.33
Grand fir	19.81	42	33	.79
Western redcedar	21.95	10	10	1.00
Western hemlock	22.56	15	14	.93

$\chi^2 = 29.38$, d.f. = 4, prob. of larger $\chi^2 = 0.0005$.

[1] Average height at 50 years (meters) of all conifer species in the series obtained from Cooper and others (in press); Pfister and others (1977); Steele and others (1981).

[2] Includes the single mountain hemlock series plot.

[3] Includes the single ponderosa pine series plot.

Armillaria. The distribution on the more productive series seems essentially continuous (table 2). Within the grand fir series, two habitat types characterized as hot-dry (CARU and SPBE) failed to yield *Armillaria*. Of the 60 remaining plots, only two (one ABGR/CLUN and one TSHE/CLUN) failed to yield *Armillaria*.

There was good continuity between habitat types where *Armillaria* was and was not found, regardless of geographic location. For example, *Armillaria* was absent from cold-dry habitat types (ABLA/VASC and ABLA/XETE) on both northern (Flathead, Kootenai, Lolo, and St. Joe) and southern (Payette, Boise, and Wallowa-Whitman) National Forests. On the other hand, if one of the habitat types that supported *Armillaria* elsewhere (for instance, ABLA/CLUN) occurred near ABLA/VASC or ABLA/XETE, *Armillaria* was present as shown by the triangles (auxiliary plots with, random plots without) on figure 1.

Epiphytic Rhizomorphs

When *Armillaria* was found, records included presence or absence of typical rot, fans, and rhizomorphs. Quantitative data about rhizomorph biomass were not recorded, but variation in the ease of finding rhizomorphs was evident.

Rhizomorph occurrence on living hardwoods (or dead portion of a living clump), dead conifers, and the various species of living conifers showed significant variation by chi-square analysis (table 3). Rhizomorphs were found on about 40 percent of the healthy conifer root systems of sapling or larger sized trees. There were also significant differences between conifer species (significant heterogeneity chi-square in table 4), particularly with Douglas-fir and grand fir.

Table 2—Delineated habitat types and status of *Armillaria* spp. on 120 0.04-ha plots randomly located within 15 National Forests of the Northern Rocky Mountains

Habitat type[1]	Average site index[2]	Climatic characterization	Number of plots	Percentage with *Armillaria*
PIPO/SYAL	15.5	Hot and dry	1	0
PSME/JUCO	9.8	Hot and dry	2	0
PSME/VAGL	14.9	Cool and dry	2	100
PSME/CARU	15.2	Hot and dry	6	0
PSME/VACA	16.2	Frost pocket	1	0
PSME/PHMA	17.7	Warm and dry	6	67
ABLA/VASC	12.8	Cold and dry	8	0
ABLA/MEFE	14.3	Cold and moderate	6	83
ABLA/ALSI	14.6	Cold and moderate	2	100
ABLA/VAGL	14.9	Cool and dry	3	100
ABLA/VACA	15.2	Frost pocket	2	0
ABLA/XETE	15.8	Cold and dry	6	0
ABLA/CACA	17.4	Cold and wet	1	0
ABLA/ACGL	18.0	Cool and dry	1	100
ABLA/CLUN	19.8	Cool and moderate	5	80
ABLA/STAM	21.9	Cold and wet	1	0
ABGR/LIBO	16.5	Warm and dry	3	67
ABGR/CARU	18.0	Hot and dry	1	0
ABGR/XETE	18.6	Cool and moderate	5	100
ABGR/VAGL	19.2	Cool and dry	5	100
ABGR/CLUN	21.0	Cool and moderate	12	92
ABGR/PHMA	22.3	Warm and dry	6	100
ABGR/ASCA	22.6	Cool and moderate	4	100
ABGR/SPBE	24.1	Hot and dry	6	0
THPL/ASCA	21.3	Warm and moderate	3	100
THPL/ATFI	21.6	Warm and wet	1	100
THPL/CLUN	21.9	Warm and moderate	3	100
THPL/ADPE	23.5	Warm and wet	3	100
TSHE/CLUN	22.6	Warm and moderate	11	91
TSHE/GYDR	22.9	Warm and wet	1	100
TSHE/ASCA	23.8	Warm and moderate	3	100

[1] Species identification: PIPO = *Pinus ponderosa*, PSME = *Pseudotsuga menziesii*, ABLA = *Abies lasiocarpa*, ABGR = *Abies grandis*, THPL = *Thuja plicata*, TSHE = *Tsuga heterophylla*, SYAL = *Symphoricarpus albus*, JUCO = *Juniperus communis*, VAGL = *Vaccinium globulare*, CARU = *Calamagrostis rubescens*, VACA = *Vaccinium caespitosum*, PHMA = *Physocarpus malvaceus*, VASC = *Vaccinium scoparium*, MEFE = *Menziesia ferruginea*, ALSI = *Alnus sinuata*, XETE = *Xerophyllum tenax*, CACA = *Calamagrostis canadensis*, ACGL = *Acer glabrum*, CLUN = *Clintonia uniflora*, STAM = *Streptopus amplexifolius*, LIBO = *Linnaea borealis*, ASCA = *Asarum caudatum*, SPBE = *Spiraea betulifolia*, ATFI = *Athyrium felix-femina*, ADPE = *Adiantum pedatum*, GYDR = *Gymnocarpium dryopteris*.

[2] Average height at 50 years (meters) of all conifer species in the series obtained from Cooper and others (in press); Pfister and others (1977); Steele and others (1981).

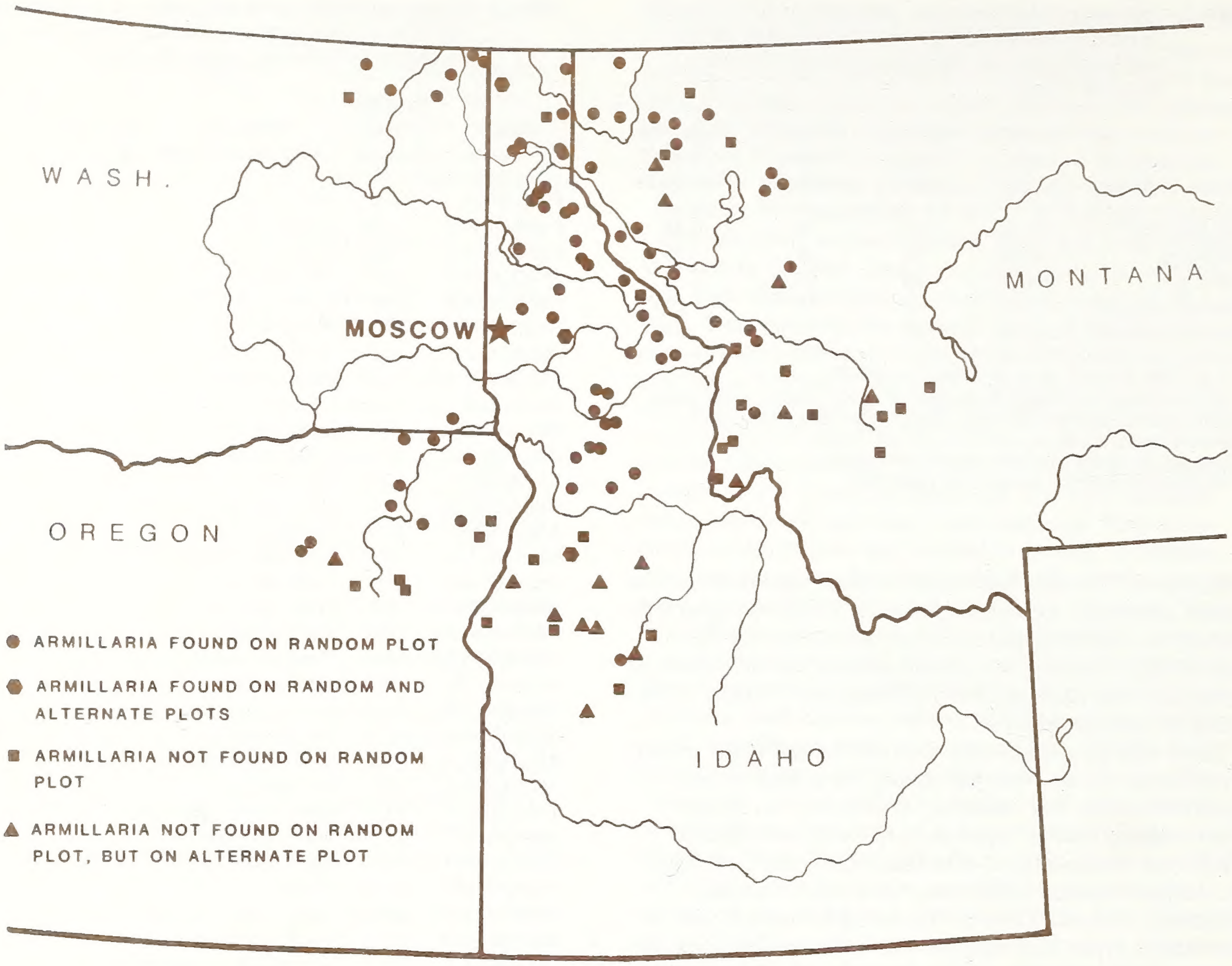
WASH.
MONTANA
MOSCOW
OREGON
IDAHO
● ARMILLARIA FOUND ON RANDOM PLOT
⬢ ARMILLARIA FOUND ON RANDOM AND ALTERNATE PLOTS
■ ARMILLARIA NOT FOUND ON RANDOM PLOT
▲ ARMILLARIA NOT FOUND ON RANDOM PLOT, BUT ON ALTERNATE PLOT

Figure 1—Location of *Armillaria* survey plots installed in 1983.

Table 3—Incidence of *Armillaria* spp. rhizomorphs on healthy and dead conifers or healthy hardwoods growing on randomly located 0.04-ha plots within habitat types supporting *Armillaria* spp. in Northern Rocky Mountain National Forests

Materials	Number plants inspected	Number with rhizomorphs	Proportion with rhizomorphs
Healthy hardwoods	203	162	0.80
Dead conifers	110	95	.86
Healthy conifers	380	164	.43

$\chi^2 = 107.48$, d.f. = 2, prob. of larger $\chi^2 = 0.0005$.

Table 4—Incidence of culturally verified *Armillaria* spp. rhizomorphs on healthy conifers growing within habitat types supporting *Armillaria* spp.

Conifer species	Number plants inspected	Number with rhizomorphs	Proportion with rhizomorphs
Ponderosa pine	18	6	0.33
Lodgepole pine	39	12	.31
White pine	19	6	.32
Douglas-fir	72	39	.54
Western larch	51	22	.43
Western hemlock	14	8	.36
Western redcedar	25	5	.20
Engelmann spruce	50	16	.32
Grand fir	61	39	.64
Subalpine fir	31	11	.35

$\chi^2 = 26.33$, d.f. = 9, prob. of larger $\chi^2 = 0.005$.

DISCUSSION

Geographic Distribution

Habitat type identification to characterize plant communities is becoming a standard tool of forest management in the Inland West. The techniques of vegetation analysis are well documented (Cooper and others in press; Pfister and others 1977; Steele and others 1981). In this study, we applied these techniques to the analysis of vegetation on 400-m^2 plots. In a few cases, where vegetation indicated a habitat undefined for that region, we applied habitat type definitions from adjacent forests, providing that other evidence also supported a correspondence of habitat types.

The dichotomy observed in this study between presence and absence of *Armillaria* agrees in general with findings in Australia (Kile 1980, 1981) where Australian *Armillaria* spp. also did not occur on very dry sites. In this study, the warmest and driest habitat types of the PSME series, as well as coldest and driest habitat types of the ABLA series and the "frost pocket" sites exemplified by the ABLA/VACA and PSME/VACA habitat types, did not seem suitable for *Armillaria*. The absence of *Armillaria* from the two cold-wet sites (ABLA/CACA and ABLA/STAM) indicates that both excessive cold and excessive moisture might limit growth and development of *Armillaria*.

The presence-absence dichotomy of *Armillaria* spp. occurrence prevailed when we examined moist auxiliary plots adjacent to dry or cold random plots (see fig. 1 for location of auxiliary plots). Also, the occurrence of *Armillaria* on all of the plots randomly located on the Coeur d'Alene, Clearwater, and Nez Perce National Forests, an area of approximately 5 million acres, reinforces these ideas. The five instances of discontinuous distribution (one plot in each of ABLA/MEFE, ABLA/CLUN, ABGR/LIBO, ABGR/CLUN, and TSHE/CLUN), where continuous distribution was expected, could be attributed to misidentified habitat type, a transitional state between suitable and unsuitable habitat types, or stand history (possibly wildfire) that prevented establishment of the fungus or recently eradicated it. The ABLA/MEFE plot was probably in transition to the ABLA/XETE habitat type, and the ABGR/LIBO could be transitional to ABGR/CARU. Influential factors of stand history are a particularly attractive explanation of the absence of the fungus from the ABLA/CLUN and ABGR/CLUN plots because the two fir series plots were located about 1,600 m apart in the same drainage of western Montana. We have no ready explanation for the absence of *Armillaria* from one TSHE/CLUN plot.

The evidence from this study concerning *Armillaria* spp. distribution can be summarized in the following hypothesis: Any 0.04-ha plot of forest land in the TSHE and THPL series located in the Northern Rocky Mountains will yield *Armillaria*. All the ABGR series in this region, except the SPBE and CARU habitat types, will also yield *Armillaria*. Greater discontinuity exists within the ABLA and PSME series. Only two PSME habitat types support *Armillaria*; these are VAGL and PHMA. In fact, the limiting conditions may be at the phase level within these habitat types. Four ABLA series habitat types support *Armillaria*. These are ALSI (*Alnus sinuata*), VAGL (*Vaccinium globulare*), MEFE (*Menziesia ferruginea*), and CLUN (*Clintonia uniflora*); however, they may show discontinuities at the phase level. We further hypothesize that *Armillaria* is absent from both the ponderosa and limber pine (*Pinus flexilis*) series. *Armillaria* spp. will behave in the mountain hemlock (*Tsuga mertensiana*) series as they do in the ABLA series. We have no information about the Engelmann spruce series.

Epiphytic Rhizomorphs

Our frequency of encountering epiphytic rhizomorphs is similar to that of Kile (1980, 1981), who encountered epiphytic rhizomorphs on 85 percent of the dead eucalypts (stumps, fire killed, and so forth) inspected. We found rhizomorphs on 86 percent of the dead conifers inspected on habitat types that supported the fungus. He found 20 percent of 202 healthy eucalypts supporting epiphytic rhizomorphs. We found 43 percent of the healthy conifers and 80 percent of the healthy hardwoods (or dead portions of healthy clumps) supporting epiphytic rhizomorphs. These values are based on a large sample and therefore provide good estimates of the probability of encountering epiphytic rhizomorphs on these materials in the Inland West in habitat types suitable for *Armillaria*.

CONCLUSIONS

Results presented in this paper indicate that risk to *Armillaria* spp. in the Northern Rocky Mountains can be predicted by habitat type. The cold-dry and hot-dry sites seemingly are outside the ecological range of all forms of *Armillaria* native to the Northern Rocky Mountains. These hypothesized patterns of occurrence must be validated before being put to general use for predicting risk of *Armillaria* root rot. This technique of risk prediction has potential application throughout the Western United States, both for *Armillaria* and for other endemic diseases of forest trees. This approach could be particularly effective for predicting the range and presence of root pathogens of woody plants. The occurrence and function of these fungi are likely tied to long-term soil and climatic conditions, similar to the occurrence of indicator plants.

Perfecting a risk-prediction system will entail additional research. We must do more fieldwork to learn the geographic and host ranges of *Armillaria* spp. clones. This will enhance our knowledge of ecological genetics of the *Armillaria*-conifer interaction. We must also taxonomically classify *Armillaria* clones. Effective progeny testing awaits development of techniques to measure host vigor and susceptibility, along with fungus pathogenicity. Regardless of the ultimate findings of such research, the findings reported here clearly indicate that forest managers will need to know habitat type of stands in the Northern Rockies if they are to account for potential *Armillaria* damage in their management plans.

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Random sampling on 15 National Forests in the Northern Rocky Mountains revealed that *Armillaria* spp. were absent from cold-dry and hot-dry habitat types and were nearly always present in the cool-moist to warm-moist habitat types.

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